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Ministry of Transportation and Highways

OPEN-GRADED ASPHALT AND SUPERPAVE PAVEMENTS

Assessment of Traffic Noise Reduction Effects

March 2000

Ministry of Transportation and Highways
Engineering Branch
Environmental Services Section

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Abstract:	The noise reduction properties of test sections of Open-Graded Asphalt (OGA) laid on Highway 19 and the Duke Point Highway in the Nanaimo area and a test section of Superpave laid on Highway 1 west of Hope were examined. OGA is known for its excellent drainage properties and can also provide relief in traffic noise exposures by dissipating tire air compression release. The Superpave process produces courser mix asphalts with somewhat rougher surfaces than standard pavements that lowers highway traffic noise by reducing tire air compression release.
Comments	After 4 years of use, OGA still provides noise reduction in the order of 3 to 4 dBA. This reduction lowers traffic noise by approximately 30%. OGA also reduces or eliminates high frequency tire noise. When compared to existing standard pavement, Superpave reduces traffic noise levels by approximately 2.6 dBA..
Key Words:	Open-Graded Asphalt, OGA, Superpave, pavement, paving, traffic noise reduction, tire whine, Nanaimo, Duke Point, Highway 1, Highway 19, Hunter Creek, Laidlaw

OPEN-GRADED ASPHALT AND SUPERPAVE PAVEMENTS: *ASSESSMENT OF TRAFFIC NOISE REDUCTION EFFECTS*

Prepared For:

Environmental Services Section
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Ministry of Transportation and Highways
Victoria, B.C.

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March 15, 2000

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SUMMARY

In 1995, the B.C. Ministry of Transportation and Highways (MoTH) paved a 1.6 km section of Highway 19 in Nanaimo with Open-Graded Asphalt (OGA), a pavement which, due to the porous nature of its surface, produces less tire noise than ordinary asphalt and has superior drainage properties. Under a three-year contract extending from 1995 to 1998, ***Wakefield Acoustics Ltd.*** has annually monitored the noise levels produced by traffic on this OGA test section and reported any changes in the apparent noise reduction effectiveness of the OGA pavement. In June, 1999, the MoTH Environmental Services Section requested that the linear study of Highway 19 OGA traffic noise levels be extended to a fourth year. It was also requested that a follow-up noise assessment be made on the OGA pavement applied in 1997 on the Duke Point Highway and that the noise reduction properties of Superpave (a quite widely used asphalt pavement with some of the open-surfaced properties of OGA) be assessed on one of the sections of Highway 1 in the Fraser Valley which were scheduled for repaving during the summer of 1999. This report presents the results of all three of these pavement noise assessments and, in addition, provides some results of preliminary investigations which ***Wakefield Acoustics Ltd.*** conducted into the effects of the Duke Point Highway OGA on the "whine" produced by heavy truck tires.

North Nanaimo Highway 19 OGA Test Section After Four Years

The noise assessment carried out at the Highway 19 test section on September 14, 1999 after the OGA had been in place for four years, showed that the trends of decreasing Highway 19 traffic volumes (most markedly following the 1997 opening of Nanaimo Parkway) and of decreasing traffic noise levels observed between 1995 and 1998, had continued. The total hourly traffic volume on Highway 19 (based on a manual counts made during the noise measurements) was 1,699 vph compared to 1,884 vph counted in September 1998 and 2,300 to 2,500 vph obtained on various occasions in 1995. Similarly, the equivalent sound level, or L_{eq}, measured over a 1.5-hour, late morning period on September 14, 1999 was 68.3 dBA compared to 69.2 dBA measured in 1999 and 75.1 dBA measured in 1995 prior to the laying of the OGA pavement. About half of the 0.9 dBA difference between the 1998 and 1999 measurement results may be attributed to the roughly 10% lower traffic volumes observed during the 1999 measurements.

Physically, the OGA pavement in the vicinity of the test site appears to be standing up well and shows no signs of surface failure, ravelling or rutting.

Duke Point Highway OGA After Two Years

The initial assessment of the performance of the OGA applied to a portion of the Duke Point Highway was conducted on July 28, 1997 shortly after the new highway was opened. Simultaneous noise measurements were made at two locations along the highway having the same traffic volumes and nominally the same average vehicle speeds. One section, however,

was paved with OGA and the other with standard asphalt. In 1997, the observed difference in the traffic L_{eq}'s measured at a distance of 15 m from the centre of the outside, westbound lane was 4.8 dBA. These measurements were repeated on September 14, 1999. The observed noise reduction effect of the OGA pavement after slightly more than two years of service, was 4.7 dBA - virtually the same as measured upon the Duke Point Highway's opening and corresponding to approximately a 30% reduction in the perceived loudness of the traffic noise. It is then clear that the OGA's noise reduction performance has not been significantly reduced over this time frame. Further, physical condition of the OGA is still very good, with no signs of deterioration being revealed by a visual inspection of the noise measurement area.

Highway 1 (Hunter Creek to Laidlaw) Superpave Noise Measurements

In the summer of 1999, roadside noise measurements were made along both sides of a straight, level section of Highway 1 between Hunter Creek and Laidlaw both before and after the highway was repaved with Superpave. Heavy truck traffic volumes were tallied during both before (July 20) and after (August 24) measurements and were found to be slightly higher in the eastbound lanes during the latter. After adjusting the L_{eq} measured near the eastbound lanes for this change in truck volumes, it was found that the overall noise reduction effect of the new Superpave over the previous somewhat worn standard asphalt pavement was 2.6 dBA. This noise level reduction corresponds to approximately a 16% reduction in the perceived loudness of the traffic noise, or roughly half the effect produced by the Duke Point Highway OGA application.

Truck Tire Whine Experiments

In order to gain some understanding of the effects of OGA on the whine produced by some heavy truck tires, noise measurements were carried out in March, 1999 on the Duke Point Highway near the western transition point between the OGA and standard asphalt pavements. Because of its intensity and tonal nature, this whine can typically be heard at quite large distances from a highway and, as such, is often a prominent contributor to community disturbance and annoyance due to highway noise. By rapidly recording narrow-band noise spectra at various locations near the pavement transition point as trucks passed from OGA to standard asphalt or vice versa, effects of OGA on whine production were observed. While these investigations were far from exhaustive, and were outside the scope of the present MoTH contract, some preliminary observations may be reported:

- not all heavy trucks produce tire whine, nor does OGA always produce a significant reduction in this whine when it occurs,
- for some heavy truck which did produce pronounced tire whine, the whine was reduced substantially (by up to 10 dB) when the truck was on the OGA section,
- the mechanisms by which OGA acts to reduce tire whine are not yet fully understood, and while some may similar to those that act to reduce general tire noise, other unique phenomena may be involved as well.

1.0 INTRODUCTION

1.1 Background

In September of 1995, the B.C. Ministry of Transportation and Highways (MoTH) paved a 1.6 km section of Highway 19 in Nanaimo with Open-Graded Asphalt (OGA). Due to the porous nature of its surface, OGA has superior drainage properties when compared to normal asphalt pavements and also significantly reduces the generation of noise by tires, particularly at highway speeds. Prior to 1995, OGA pavements had not been used to any significant degree on B.C. highways so that the Nanaimo application was to serve as a demonstration project to provide, under local coastal conditions, knowledge of OGA's surface drainage and noise reduction properties and their longevity, as well as the physical durability of the pavement.

Wakefield Acoustics Ltd. was retained by the MoTH Environmental Services Section in 1995 to assess the traffic noise reduction effects of the Nanaimo OGA pavement installation, both immediately before and after the OGA was applied and after one, two and three years of service. The results of this three-year study were documented in Report 95-M105-4 of Janaury, 1999. In June, 1999, the Environmental Services Section requested that Wakefield Acoustics Ltd. extend the linear study of the Nanaimo OGA noise reduction performance to a fourth year. In addition, noise assessments were requested on another section of OGA pavement that had been laid in 1997 on part of the Duke Point Highway as well as a section of the Trans Canada Highway (Hwy 1) in the Fraser Valley that was scheduled to be repaved with "Superpave" during the summer of 1999. Superpave is a relatively new asphalt pavement design that is being applied quite widely in North America and has some of the characteristics of OGA in that its surface is somewhat porous. This report describes the procedures followed in assessing the noise reduction characteristics of these various asphalt pavements and presents the results.

1.2 Scope

The scope of this pavement noise assessment has then been:

- assess the noise output from the Highway 19 OGA test section in Nanaimo after four years of service,
- compare the traffic noise levels generated by both the OGA and regular asphalt pavement sections of the Duke point after over two years of service,
- assess "before and after" noise levels on a section of the Highway 1 which was resurfaced with "Superpave" in the summer of 1999,
- additional measurements, beyond the original study scope, were made of the noise produced by individual heavy trucks as they passed between the OGA and standard asphalt sections of the Duke Point Highway. The intent was to assess the effect of OGA on the tonal noise (whine) produced by heavy truck tires,
- submit results of study, first in an Interim (draft) and then in a Final Report.

2.0 HIGHWAY 19 (NANAIMO) OGA AFTER FOUR YEARS OF SERVICE

2.1 Methodology

When the OGA test section in north Nanaimo (between Northfield and Dorman Roads) was first paved in 1995, noise measurements were also made at a control (standard asphalt) section just north of the OGA section which had nominally the same traffic characteristics. However, less than a year later, the control section was also paved with OGA. With the loss of the control section, OGA noise measurements in subsequent years were limited to a linear study of the OGA test section itself. It was therefore necessary to make appropriate corrections to the measured traffic noise levels for any year-to-year variations in traffic volumes, heavy truck mix and average vehicle speed. One particularly significant variation in traffic conditions involved the transfer of traffic from Highway 19 to the Nanaimo Parkway following the latter's opening on May 31, 1997. A similar approach has been taken in the extension of the linear study of OGA noise reduction performance to a fourth year.

The noise measurements were made on September 14, 1999 at the usual location on the west side of Highway 19 approximately in the middle of the OGA test section. Figure 2.1 provides photographs of the test site as well as close up of the OGA pavement. As in all previous measurements, the microphone of the Larson-Davis Model 820 Community Noise Analyzer was located 15 m from the centreline of the southbound lanes. A series of 15-minute samples of the traffic noise were measured between 10:45 and 12:15 hours. Categorized traffic counts were also made in both northbound and southbound directions between 11:00 and 12:00 hours. It had been intended to establish the average vehicle speed as well. However, on this occasion, the rented K35 doppler radar speed detector malfunctioned. Therefore, while no vehicle speed data were collected, weather conditions were fair (about 20° C with very light breezes from north) and there was no maintenance work or other activities on this section of Highway 19 that might have influenced average vehicle speed. It has then been assumed that the average vehicle speed was typical of this location and was effectively the same as that observed during the previous September 10, 1998 measurements.

2.2 Results of September 1999 Traffic Noise Assessment

2.2.1 Traffic Volumes and Heavy Vehicle Mix

Table 2.1 summarizes the Highway 19 traffic volumes and heavy vehicle mixes observed over the four years since the OGA pavement was laid. It is seen that a significant decrease in both total volumes and heavy vehicle mix was observed in September, 1998, apparently as a result of the opening of the Nanaimo Parkway the previous year. On September 14, 1999, the two-directional traffic volumes counted on Highway 19 were 1,699 vph. This represents a decrease of approximately 10% compared to the September 10, 1998 counts and is perhaps indicative a further shift of traffic to the Parkway.

At 2.1%, the heavy vehicle (heavy trucks and busses) mix has remained the same as observed in 1998, therefore continuing to reflect a substantial transfer of truck traffic to the Parkway.

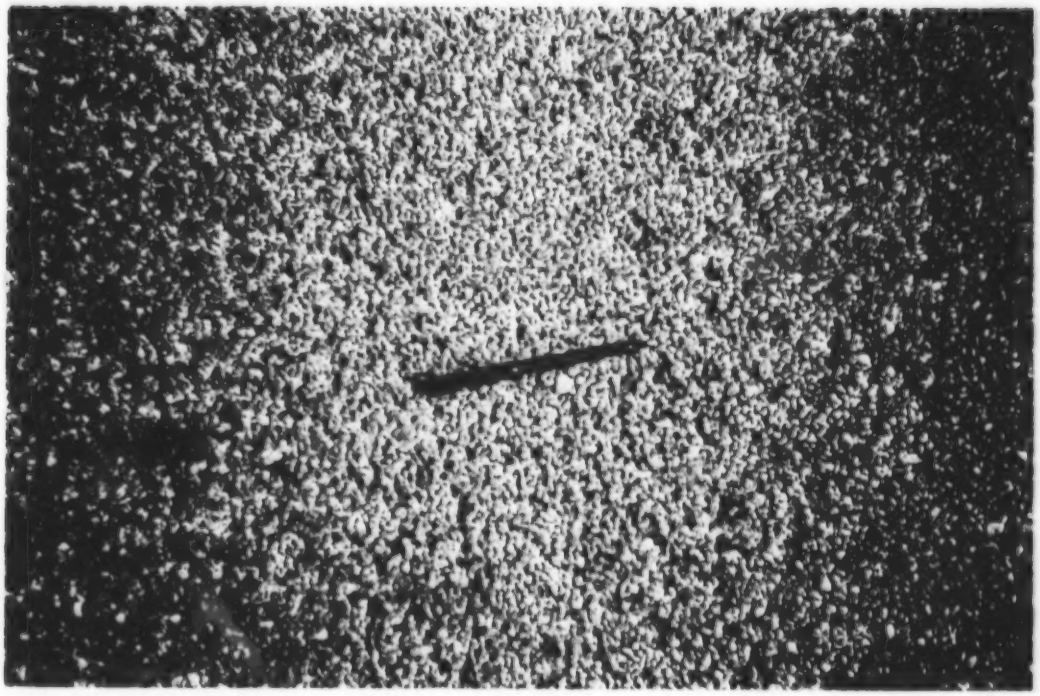

Figure 2.1; Upper Photo - View from OGA Noise Measurement Site in North Nanaimo Looking East Towards Highway 19; Lower Photo - Close-up of OGA Pavement after Four Years of Service.

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Study Phase	Measurement/ Count Date	Total Traffic Volume (vph)	Heavy Vehicle Mix (%)	Average Vehicle Speed (kmph)
1	07-09-95	2,420	7	78.9
	28-09-95	2,500	4.6	-
	28-09-95 (MoTH)	2,290 (4-hr. average)	-	-
	04-10-95	-	-	78.1
	18-10-95	2,125	5.3	78.6
2	24-05-96	2,690	3.8	-
	10-09-96	2,440[1]	5.0	74.3
3	21-05-97	2,482	3.0	73.3
	22-05-97	2,418[1]	5.2	73.9
	23-05-97	2,216[1]	5.8	73.0
4	10-09-98	1,884[1]	2.1	71.8
1999 Extension	14-09-99	1,699	2.1	-
Average		**2,288[3]**	**4.4[4]**	**75.2**
Standard Deviation[2]		**290.4[3]**	**1.6[4]**	**2.8**

1. These 2-directional volumes were taken to be twice the counted southbound traffic volumes.
2. These are the standard deviations of the average volume and speed values obtained on each of the measurement dates listed.
3. Prior to inclusion of Phase 4 and "1999 Extension" (i.e., post-Nanaimo Parkway) traffic data, the average traffic volume on Highway 19 was 2,398 vph while the standard deviation of these volumes was 167.5 vph.
4. Prior to inclusion of Phase 4 and "1999 Extension" (i.e., post-Nanaimo Parkway) traffic data, the average heavy vehicle mix on Highway 19 was 5.0% while the standard deviation was 1.2%.

Table 2.1; Summary of Highway 19 Traffic Flow Parameters Observed During Phases 1, 2, 3 and 4 of the Initial OGA Pavement Noise Reduction Study and during the "1999 Extension".

Study Phase	Measurement/ Count Date	Total Traffic Volume (vph)	Heavy Vehicle Mix (%)	Average Vehicle Speed (kmph)
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Table 2.1; Summary of Highway 19 Traffic Flow Parameters Observed During Phases 1, 2, 3 and 4 of the Initial OGA Pavement Noise Reduction Study and during the "1999 Extension".

2.2.2 Results of Equivalent Sound Level (L_{eq}) Measurements

Table 2.2 summarizes the results of the noise measurements made over the four years since the OGA pavement was laid on Highway 19. It is seen that the equivalent sound levels, or L_{eq}'s, measured between the application of the OGA and the opening of the Nanaimo Parkway have been consistently between 71 and 72 dBA. By September, 1998, when the Parkway had been open for over a year, the average noise level had decreased by about 2 dBA to 69.2 dBA.

The individual 15-minute measurements conducted during the 1.5 hours of late-morning monitoring on September 14, 1999 produced very consistent results. The L_{eq} (15 min)'s ranged from 67.9 to 68.5 dBA, with the average value over the full 90 minutes being 68.3 dBA. Average traffic noise levels then appear to have experienced a further reduction of 0.9 dBA relative to the 69.2 dBA observed in 1998. Approximately half of this difference may be attributed to lower traffic volumes. Referring to Table 2.1 it is seen that the total traffic volume in September 1999 was 1,699 vph compared to 1,884 vph in 1998. All else being equal (and heavy vehicle mix was unchanged), this 10% reduction in volume would be expected to produce about a 0.5 dBA reduction in L_{eq}.

It is then seen that, when corrected for traffic volume variation, the results of the September 1998 and 1999 measurements are within 0.4 dBA of each other - this difference is slightly less than the nominal accuracy limits of the instrumentation. ***It may then be concluded that the noise reduction performance of the OGA pavement on Highway 19 in Nanaimo has not changed significantly during the fourth year of its service. Due to the combination of OGA and traffic volume reduction, the overall noise exposures along this stretch of Highway 19 are now approximately 6.8 dBA lower (or about 38% quieter) than they were in early September 1995***

2.3 Physical Condition of OGA Pavement after Four Years of Service

The noise reduction effect of OGA pavement stems from its surface voids which permit air trapped within the tread patterns of rolling tires to vent before it can be compressed and released, resulting in the generation of broad-band tire noise. Figure 2.1 includes a photo of taken September 14, 1999 the OGA pavement at the Highway 19 test site. It is seen that the surface porosity of the OGA has been largely maintained and that, while the inner pavement voids have no doubt accumulated a certain amount of dust and tire particles, this void filling has not yet approached the stage where it has begun to affect the noise reduction performance of the OGA.

In terms of it physical condition, the OGA pavement in the vicinity of the test site appears to be standing up well and shows no signs of surface failure, ravelling or rutting.

Study Phase	Measurement Date (Pavement Status)	Measured L_{eq} (dB)		L_{eq} Difference (dB) (Site 2 - Site 1) Measured/Normalized[1]
		Site 1 (OGA Site)	Site 2 (Regular Asphalt Control Site)	
1	September, 1995 (before OGA applied at Site 1)	75.1	73.4	-1.7
1	Sept./Oct. 1996 (after OGA applied at Site 1)	71.0	74.2	3.2/4.9
2	May 24, 1996 (prior to OGA application at Control Site 2)	71.9	74.9	3.0/4.7
2	Sept. 10, 1996 (1 year after OGA applied at Site 1)	71.2	-[2]	-[2]
3	May 21-23, 1997 (prior to Nanaimo Parkway opening)	71.1	-	-
4	Sept. 10, 1998 (3 years after OGA applied at Site 1)	69.2[3]	-	-
Additional Year (1999)	Sept. 14, 1999 (4 years after OGA applied at Site 1)	68.3[4]	-	-

1. The "Normalized" difference values include the 1.7 dBA "site correction" observed between Sites 1 and 2 during the initial, pre-OGA measurements.

2. Since the section of Highway 19 containing Site 2 was itself paved with OGA in June 1996, this site was no longer useful as a control. No further noise measurements were then made at this location.

3. The additional decrease in traffic noise levels observed on this occasion was largely due to the reductions in Highway 19 traffic volume and heavy vehicle mix which accompanied the opening of the Nanaimo Parkway in the spring of 1997. Without these reductions in traffic volumes (and also a slight reduction in average vehicle speed), Phase 4 traffic noise levels at Site 1 would be expected to have been between L_{eq} 71.2 and 71.6 dBA.

4. The traffic volume on Sept. 14, 1999 was 10% lower than on Sept. 10, 1998. This decrease in volume would be expected to account for about 0.5 dBA of the 0.9 dBA difference observed between the Leq's measured on the two occasions.

Table 2.2; Highway 19 Traffic Noise Levels Measured at Sites 1 and 2 During Phases 1 and 2 of the Initial OGA Pavement Noise Reduction Study and at Site 1 during Phases 3 and 4 of the Initial Study as well as during the "Additional Year (1999)".

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3	May 21-23, 1997 (prior to Nanaimo Parkway opening)	71.1	-	-
4	Sept. 10, 1998 (3 years after OGA applied at Site 1)	69.2[3]	-	-
Additional Year (1999)	Sept. 14, 1999 (4 years after OGA applied at Site 1)	68.3[4]	-	-

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3.0 DUKE POINT HWY - OGA NOISE REDUCTION AFTER 2.2 YEARS SERVICE

3.1 Methodology

The noise measurements made on the Duke Point Highway on September 14, 1999 were essentially a repeat of those made on July 28, 1997 shortly after the highway opened. This involved simultaneous noise measurements at two locations, both north of the highway and 15 m from the centre of the outside westbound lane. Site A (the standard asphalt, or control site) was located about 200 m west of the new Nanaimo River bridge and well beyond the transition from OGA to standard asphalt (see Figure 3.1) while Site B (the OGA site) was located about 300 m east of the Cedar Road Overpass (see Figure 3.2). Both measurement sites are on upward sloping ground and overlook the highway slightly. In this way, any noise shielding effects of the concrete roadside barrier, which is present at both sites, was minimized.

Six consecutive 15-minute noise measurements were conducted using two identical Larson-Davis Model 820 Community Noise Analyzers. These instruments comply with ANSI S1.4 [1983] for Type 1 Sound Level Meters and sample the ambient noise levels several times per second, storing the data for subsequent read and analysis. Their calibrations were checked both before and after the measurement periods. The weather during these measurements was sunny and warm (about 25°C), with very light winds from the north - ideal for outdoor noise measurements.

Traffic counts were conducted at each site for a short period, in particular to provide an indication of the heavy vehicle mix on the Duke Point Highway.

3.2 Results of Traffic Counts on Duke Point Highway

During the noise measurements, traffic counts were conducted over two 25 to 30 minute periods, one of which included the arrival of a ferry at the Duke Point terminal. Since the Duke Point Highway provides direct access to the ferry terminal as well as the Duke Point Industrial Park, its heavy truck mix is relatively high. Table 3.1 summarizes the results of these two brief traffic counts. The results indicate the effects of the arrival of a ferry on the overall traffic volumes and on the heavy truck mix. It is seen that during the first traffic count, which was completed before the ferry arrived, the heavy truck mix in the eastbound lanes (heading to ferry) was 14% while in the westbound lanes it was 35%. During the second traffic count, which included the ferry arrival, westbound traffic volumes (particularly light vehicles) not surprizingly, increased substantially while eastbound volumes were relatively unchanged. However, during this latter 30-minute period, the heavy truck mix was the same (17%) in both directions.

Since OGA acts to reduce the tire noise component of traffic noise only, its is most effective on high speed highways (as tire noise increases rapidly with speed) having relatively low heavy truck mixes (trucks tend to create more engine and exhaust noise). It is then to be expected that the OGA pavement used on Duke Point Highway, which has a heavy truck mix of about 18%, would provide even greater noise reduction on a highway with a heavy truck mix more typical of B.C. highways heavy, i.e., from 5% to 10 %.

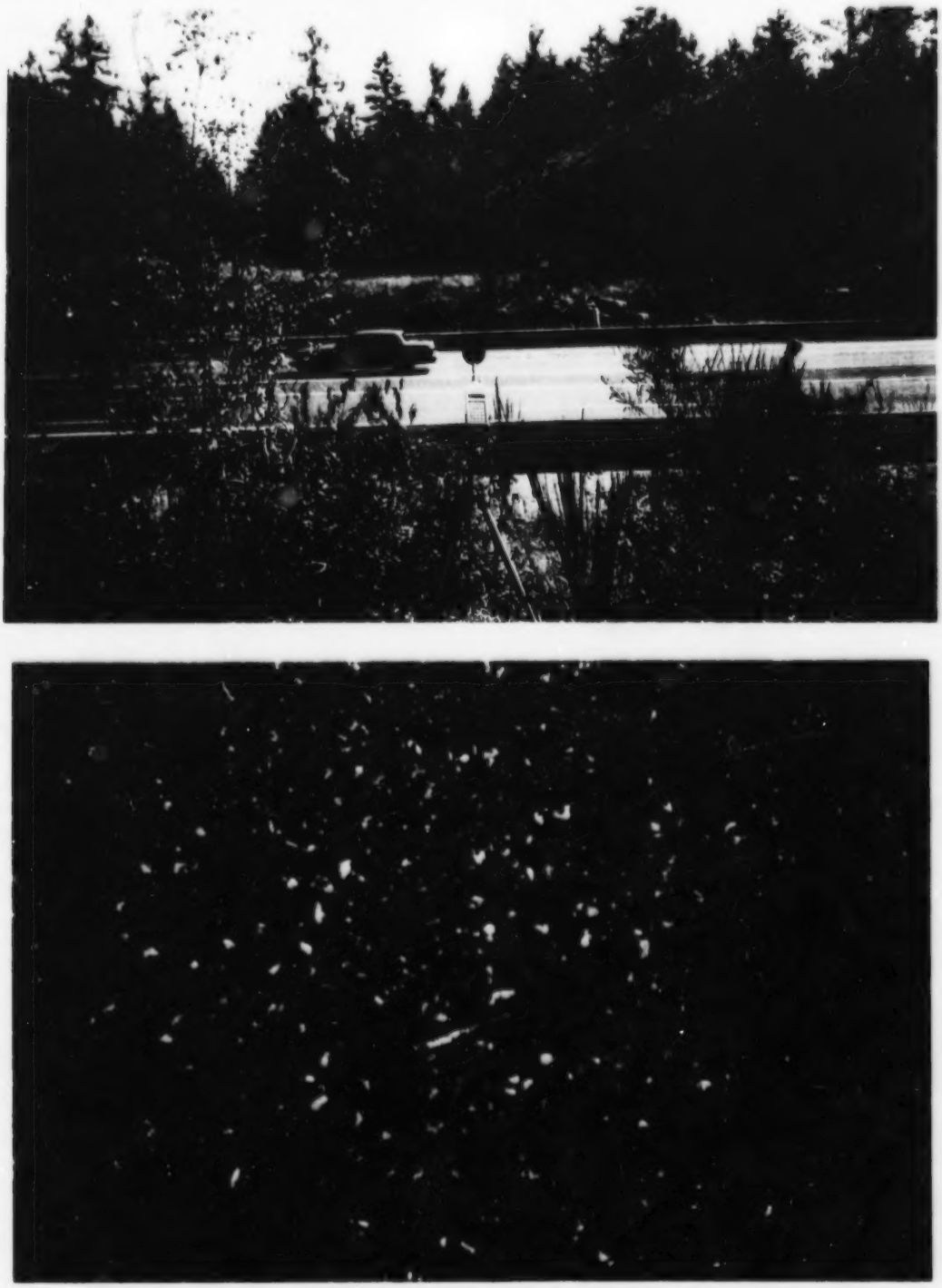

Figure 3.1; Upper Photo - **View from OGA Noise Measurement Site on North Side of Duke Point Highway Looking South Towards Highway;** Lower Photo - **Close-up of OGA Pavement After 2.2 Years of Service.**

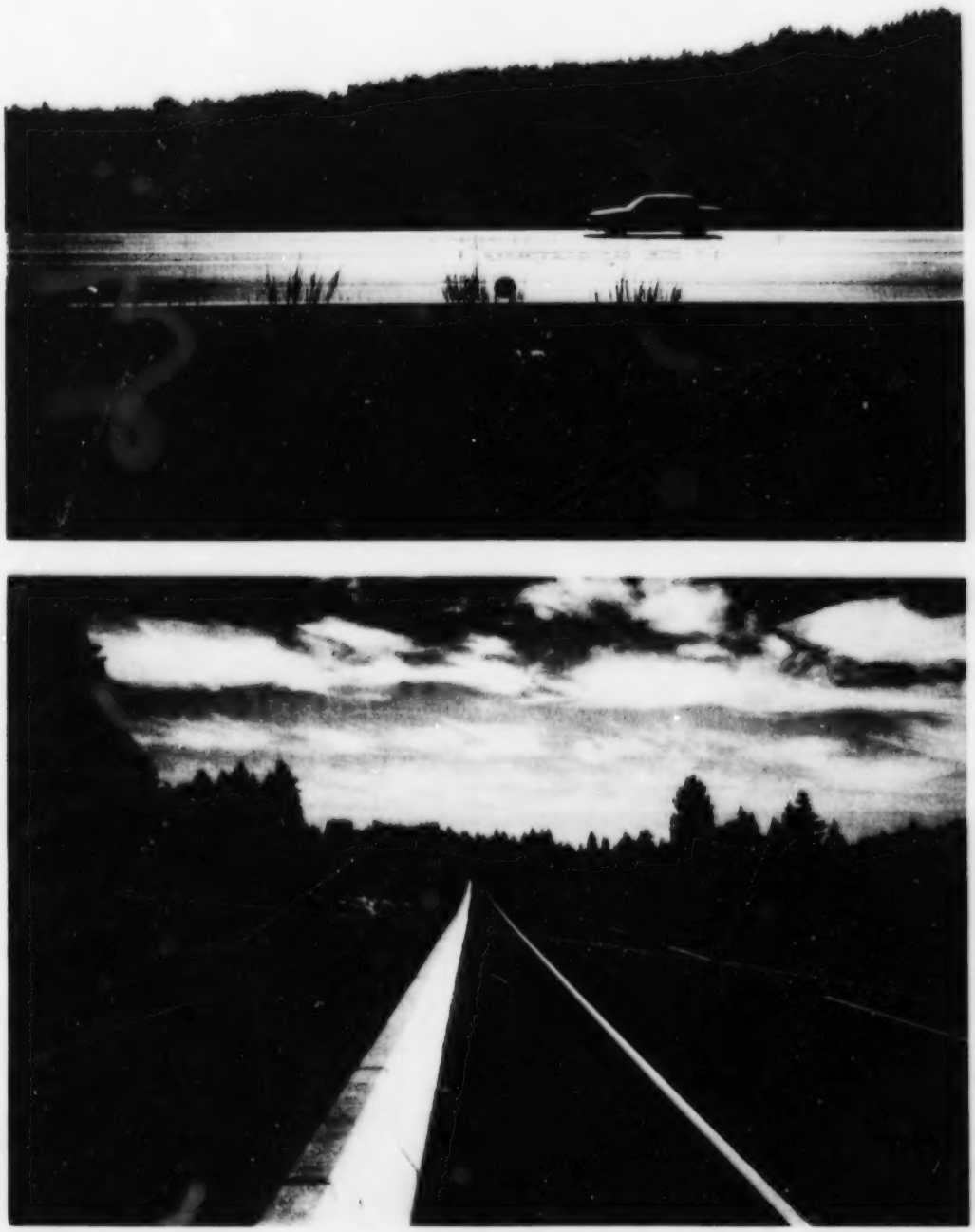

Figure 3.2; **Upper Photo - View from Standard Asphalt Noise Measurement Site on North Side of Duke Point Highway Looking South Towards Highway; Lower Photo - View to East along Duke Point Highway Towards the OGA/Standard Pavement Transition Point and the Nanaimo River Bridge.**

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Traffic Direction	First Traffic Count Period (14:16 to 14:41 hours)				Second Traffic Count Period (14:45 to 15:15 hours)			
	Light Vehicles	Medium Trucks	Heavy Trucks	Total	Light Vehicles	Medium Trucks	Heavy trucks	Total
Eastbound	81 (82%)	4 (4%)	14 (14%)	99	65 (80%)	2 (3%)	14 (17%)	81
Westbound	16 (55%)	3 (10%)	10 (35%)	29	165 (78%)	10 (5%)	37 (17%)	212
Total	97 (76%)	7 (5%)	24 (19%)	128	230 (78%)	12 (4%)	51 (17%)	293
Approx. vph	233	17	58	307	460	24	102	586

Table 3.1 Results of Traffic Counts Conducted on the Duke Point Highway, September 14, 1999

3.3 Results of September 14, 1999 OGA Noise Assessment

The simultaneous noise measurements were made in a series of 15 minute intervals starting at 14:05 hours and finishing 1.5 hours later. The monitoring period included the arrival of one ferry at the Duke Point Terminal and the resulting platoon of vehicles passing both sites. The overall 1.5 hour L_{eq}'s obtained were 68.7 dBA at the standard asphalt site and 64 dBA at the OGA site. ***The measured noise reduction effect of the OGA at a distance of 15 m from the centre of the outside lane was therefore 4.7 dBA - corresponding to approximately a 30% reduction in the perceived loudness (noisiness) of the traffic noise.*** This is then almost identical to the 4.8 dBA obtained during the initial July 28, 1997 assessment of the Duke Point Highway OGA effect which was presented in our Report No. 95-M108-3 of September 1997.

3.4 Physical Condition of Duke Point Highway OGA Pavement

After 2.2 years of service,the OGA pavement applied on part of the Duke Point Highway - a photo of which may be seen in Figure 3.1 - showed no obvious signs of physical deterioration.

3.5 Effect of Setback Distance on OGA Performance.

As sound waves spread out from a noise source such as a highway, sound energy is extracted by the air. This progress, known as "atmospheric absorption" is much more pronounced at higher frequencies than at lower ones. Therefore, as one moves farther from a highway, the noise heard becomes more dominated by the lower frequency components until, at large distances, all that remains is a low rumble and perhaps the mid-frequency whine of truck tires. Since OGA is also most effective at eliminating the mid-to-higher frequency components of tire noise from general traffic, its beneficial effect tends to diminish gradually with increasing setback distance from the highway. It is then most effective within the first few hundred metres from the highway.

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In the case of the Duke Point Highway, there are a number of rural residences, which are setback more than few hundred meters from the highway and, as such, did not qualify for mitigation consideration under the MoTH noise policy. The residents are, however, exposed to clearly audible, and for some, objectionable, levels of highway noise, particularly due to the "whine" of heavy truck tires as well as the "thumps and rattles" created by heavy trucks striking the expansion joints at either end of the new Nanaimo River Bridge. While OGA can have no effect on the latter highway noise source, based on previous observations, it appears to have some potential to reduce the generated of truck tire whine. If so, this would have the effect of enlarging the zone of benefit around a highway surfaced with OGA. Section 5.0 herein presents some preliminary findings based on measurements of heavy truck noise made on the Duke Point Highway on March 7, 2000.

4.0 HIGHWAY 1 (HUNTER CREEK TO LAIDLAW) SUPERPAVE NOISE TESTS

4.1 Methodology

During the summer of 1999, several sections of highway within the South Coast Region were scheduled to be resurfaced with "Superpave". This provided an opportunity to assess the noise reduction capabilities of OGA by conducting "before and after" noise measurements on one of these sections. The section selected for testing was located on Highway 1 between the Hunter Creek and Laidlaw Road Overpasses at eastbound Station 19.80. This section of Highway 1 is straight and flat, has a high posted speed (110 kpmh) and is 1 km from the nearest exit ramp. It therefore provided an ideal environment for testing the effects of a change in pavement on traffic noise levels. Figures 4.1 and 4.2 provide photographs of the test site and of the old standard asphalt and new Superpave pavements.

Since the highway in the test area is on a 1 m fill and is paralleled to the north by the CNR mainline, traffic noise measurements were made on both the north and south shoulder with the microphones positioned at the edge of pavement (2.2 m from outside edges of the outside lanes) and 1.5 m above the pavement level. While the noise levels obtained were not then representative of actual community noise exposures, the measurement locations were ideal for capturing any change in tire noise emissions which might accompany the change in pavement.

Noise measurements were conducted simultaneously on both sides of the highway using a Larson-Davis Model 820 Community Noise Analyzer and a Larson-Davis Model 2800 Real Time Analyzer - both ANSI S1.4 [1983] Type 1 Sound Level Meters. A series of 15 minute measurements were made beginning at 12:00 hours and ending at 13:30 hours. Both instruments yielded the Leq's, while the LD 820 provided traffic noise level statistics and the LD 2800 provided frequency spectra of the noise.

The "before" measurements were conducted on July 20, 1999 between 12:00 and 13:30 hours while the "after measurements were made on august 24, 1999 between 13:10 and 15:00 hours. Heavy vehicle counts were conducted in both directions on both occasions so that any significant variations between "before" and "after" traffic conditions could be corrected for in assessing the noise reduction effects of the Superpave.

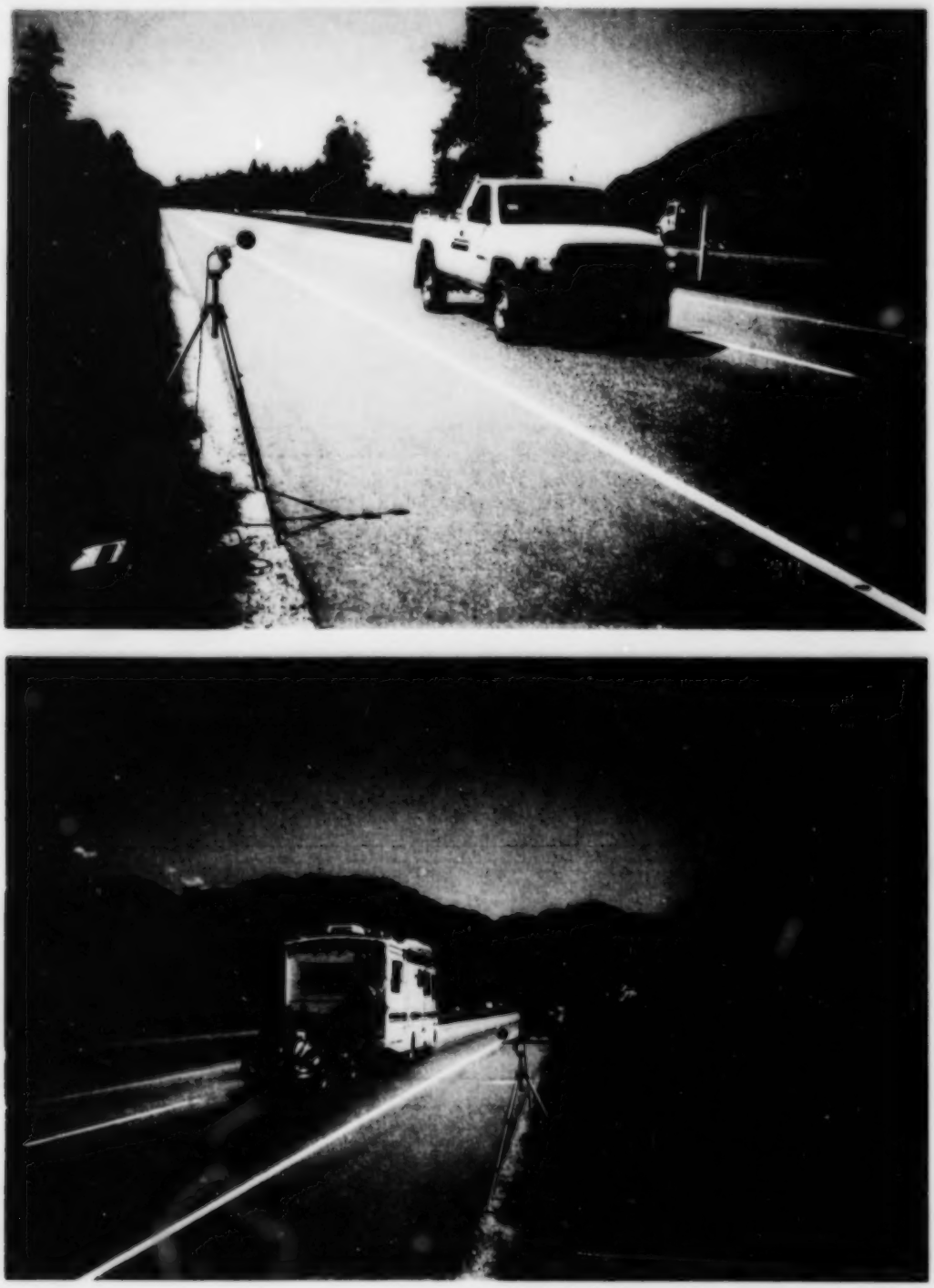

Figure 4.1; Hunter Creek to Laidlaw Superpave Noise Measurement Site (Eastbound Lanes) on the Trans Canada Highway. Upper Photo - Looking West , Lower Photo - Looking East.

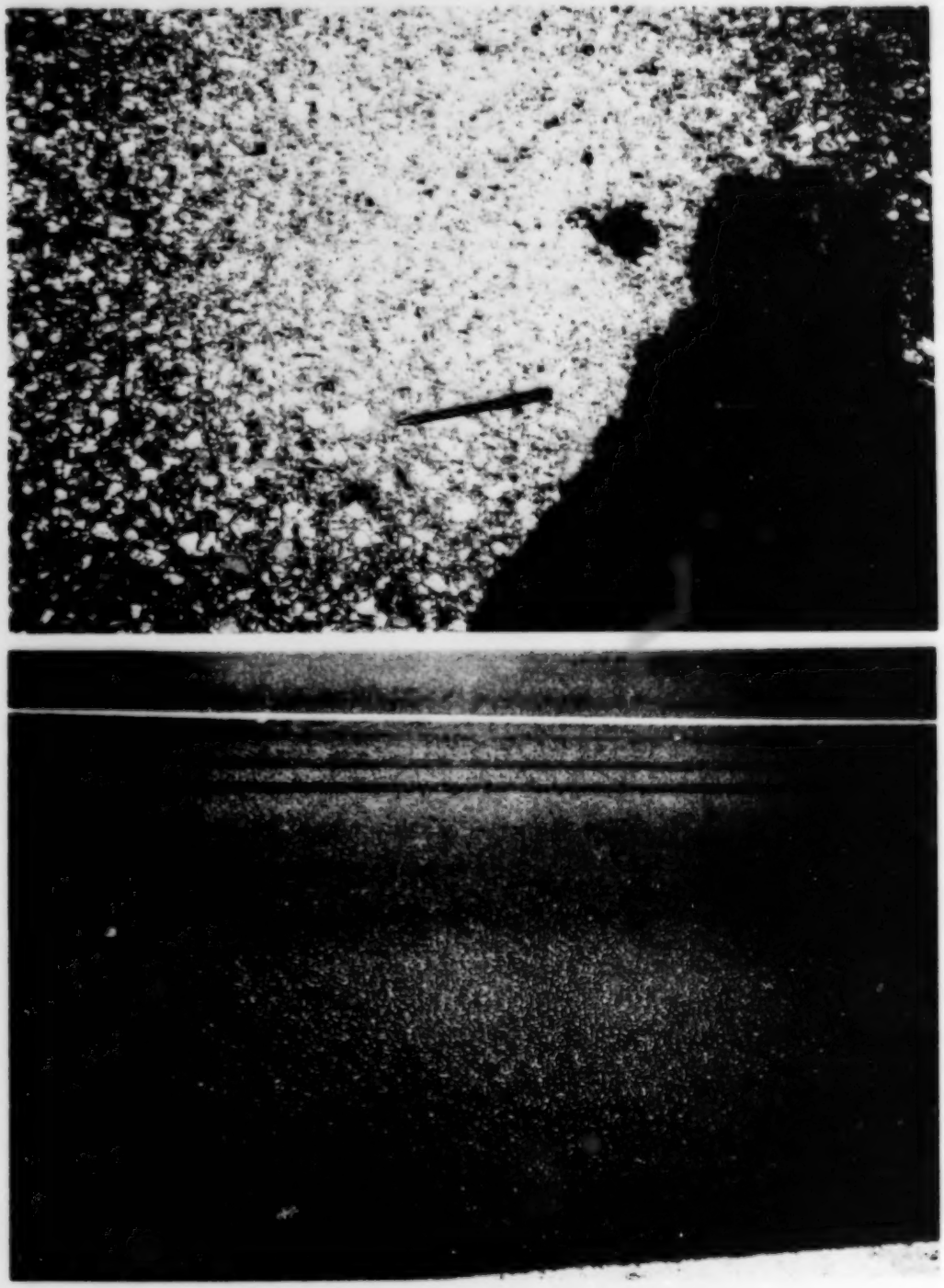

Figure 4.2; Hunter Creek to Laidlaw Superpave Noise Assessment Site on Trans Canada Highway. Upper Photo – Original Standard Asphalt Pavement before Replacement. Lower Photo – New Superpave Pavement (Note, this photo is of recent Superpave on the TCH HOV Lanes in Burnaby, rather than at Hunter Creek).

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4.2 Results of "Before and After Superpave" Noise Tests

4.2.1 Results of Heavy Vehicle Counts

Because of the relatively high proportion of heavy vehicles on Highway 1 in the study area during midday hours on weekdays and their dominance of the overall emissions of noise from the traffic stream, it was considered sufficient to count only the numbers of heavy vehicles in both eastbound and westbound directions. Any corrections between before and after Superpave noise levels would then be based on the difference in observed heavy vehicle volumes and the occasions.

The results of the heavy vehicle counts at the Superpave test site both before and after the new pavement was applied, are summarized in Table 4.1. It is seen that, on the two occasions, the heavy vehicle volumes (expressed in heavy vehicle per hour, or hvph) were quite similar. In fact, they were identical (54 hvph) in the westbound lanes, while in the eastbound lanes, they were about 15% higher during the "after" measurements. This latter increase in eastbound heavy vehicle volumes would be expected to produce an increase in the traffic noise emissions (in terms of L_{eq}) from the two eastbound lanes of at most 0.6 dBA. The increase in the overall noise emissions of all four lanes would be roughly half this much, or 0.3 dBA.

Vehicle speed measurements were not conducted as part of the Superpave noise reduction tests. It was expected that, given the free flowing nature of the traffic on Highway 1 and the absence of any access points with in the study area, there would be minimal variation in average vehicle speed between two midday periods on similar clear, warm summer days.

Traffic Direction	Before Superpave (July 20, 1999)			After Superpave (August 24, 1999)			Noise Level Correction = 10log(hvph$_a$/hvph$_b$) (dBA)
	Count Duration (hours)	Total HV's Counted	Approx. HV's/hr. (hvph$_b$)	Count Duration (hours)	Total HV's Counted	Approx. HV's/hr. (hvph$_a$)	
Eastbound	1.35	72	53	1.75	107	61	0.6
Westbound	1.38	74	54	1.75	94	54	0.0

Table 4.1 Heavy Vehicle Counts at Highway 1 (Hunter Creek to Laidlaw) Test Site - Before and After Superpave Applied.

4.2.2 Results of Traffic Noise Measurements Before and After Superpave

The results of the noise measurements carried out before and after Super pave was applied to the Hunter Creek to Laidlaw section of Highway 1 are presented in Table 4.2. It is seem that when the heavy vehicle correction is applied to the eastbound lanes noise level, the effect of the Superpave is found to be essentially the same (2.6 to 2.7 dBA) in each direction. ***The effect of the new Superpave was then to reduce the overall noise emissions of the highway (at close range) by 2.6 dBA – corresponding to about a 16% reduction in perceived loudness or noisiness.***

Traffic Direction	Equivalent Sound Level (L_{eq}) at Edge of Pavement (dBA)		(III) Heavy Vehicle Volume Correction (dBA)	(I)–(II)+(III) Superpave Noise Reduction Effect (dBA)
	(I) Before Superpave (July 20, 1999)	(II) After Superpave (August 24, 1999)		
Eastbound	81.5	79.4	0.6	2.7
Westbound	80.9	78.3	0.0	2.6
Both Directions (Average)	81.2	78.9	0.3	2.6

Table 3.2; Traffic Noise Levels Measured at Highway 1 (Hunter Creek to Laidlaw) Test Site, Before and After Superpave Applied.

4.2.3 Pavement Condition

Figure 4.2a provides a photograph of the standard asphalt that was in place on the test section prior to the application of the Superpave. While the previous pavement within the immediate vicinity of the test section showed some rutting and rock protrusion, its general condition was quite good. In order to obtain the most accurate indication of the noise control benefits of Superpave over standard asphalt, the noise measurement were made at locations where the previous pavement had no obvious structural failures (cracks, potholes, or undue roughness). However, it is still to be expected that the old, worn asphalt pavement would generate somewhat more tire noise than would new standard asphalt. Therefore, when compared to newly applied standard asphalt, the noise benefit of Superpave would be expected to be somewhat less that the 2.6 dBA observed in this case.

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Traffic Direction	Before Superpave (July 20, 1999)			After Superpave (August 24, 1999)			Noise Level Correction $=10\log(hvph_A/hvph_B)$ (dBA)
	Count Duration (hours)	Total HV's Counted	Approx. HV's/hr. ($hvph_B$)	Count Duration (hours)	Total HV's Counted	Approx. HV's/hr. ($hvph_A$)	
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	(I) Before Superpave (July 20, 1999)	(II) After Superpave (August 24, 1999)		
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5.0 EFFECTS OF OGA ON THE GENERATION OF TRUCK TIRE WHINE

5.1 Truck Tire Whine

As was discussed briefly in Section 3.4, one of the most prominent and intrusive components of highway noise, particularly at residences located some distance from the highway and in otherwise quiet neighbourhoods, is the tonal noise, or "whine", produced by certain types of tires – generally heavy truck tires but also by the lugged tires quite commonly found on pickup trucks and other utility vehicles. This whine results from the impact of successive tire ribs or lugs on the pavement as the tires roll along. The frequency (pitch) of the whine is then dependent on the spacing of the ribs/lugs and the speed of the truck. Not all truck tire treads produce a pronounced whine even on standard asphalt. However, for those which do, both the frequency of the whine and its intensity increase with truck speed.

It had been observed (with the ear) during the follow-up assessment of the Duke Point Highway OGA pavement on September 14, 1999 that the whine produced by some eastbound heavy trucks was dramatically reduced when the truck passed from the standard asphalt to the OGA just west of the Nanaimo River Bridge. While not within the scope of the present assignment, it was decided to conduct some measurements using the Larson-Davis Model 2800 Real Time Spectrum Analyzer to measure the change in frequency content of heavy truck noise as trucks passed from OGA to standard asphalt or vice versa.

5.2 Methodology

In order to obtain a series of frequency spectra of the noise emitted by trucks as they approached, crossed and moved away from the OGA/standard asphalt transition point, the LD 2800 was set for "Linear Repeat" averaging and "Autostore". The instrument then generated and stored a noise spectrum (noise level versus frequency plot) at regular intervals of 0.5 seconds in some cases and 0.25 seconds in others. The frequency analysis was done either in 1/3rd-octave bands over the entire audible frequency range (20 to 20,000 Hz.) or in 200 line spectra with a constant bandwidth of 6.25 Hz. over the more limited range from 20 to 1250 Hz. within which tire whine was generally expected to occur.

Series of truck noise spectra were recorded as described above in three different positions relative to the OGA/standard asphalt transition point:

1. ***Position 1*** - on top of the small hillock located almost directly south of the transition point and approximately 200 m from the highway. In terms of evaluating the effects of OGA on truck tire whine, this measurement position had the advantage of being far enough away from the highway that the setback distance to the microphone stayed relatively constant as the trucks passed through the pavement transition zone. Corrections for varying measurement distance would not then be required. However, while a few good samples were obtained, competing noise from aircraft and from other vehicles on the highway often prevented the clean measurement of the noise from the truck in question. In addition, at this position the CRB blocked the direct line of sight

to the tire/pavement interface and hence reduced the levels of tire whine reaching the microphone. Figure 5.1 shows a westbound truck approaching the pavement transition point as photographed from Position 1. Note, a telephoto lens was used so that the truck and highway appear much closer than they actually were.

2. ***Position 2*** - located to the north of the highway, to the west of the pavement transition point and at an elevation slightly above the highway so that the CRB did not significantly interrupt the line of sight to the tires. Figure 5.2 shows an eastbound truck having just passed the pavement transition - which may be seen in the lower right hand corner of the photo (again a telephoto lens was used). This position, being much closer to the highway, made the measurement of truck tire whine much easier and several good samples were obtained. However, because this position was located well west of the pavement transition, the noise-source (truck) to receiver (microphone) distance was changing rapidly as the truck moved through the transition zone. Accurate comparison of tire noise emissions from OGA and standard asphalt would then require correction for distance variations.

3. ***Position 3*** – in an attempt to minimize the complication of varying source receiver distance while staying close tot he highway, a third measurement position was located on the north side of the highway directly opposite the pavement transition point. Unfortunately, since the pavement transition is located on a quite high fill section, this measurement position was unavoidably located well below the highway grade and, as such, substantial shielding of the tire noise was provided by the highway shoulder and CRB. Figure 5.3 shows a truck passing the pavement transition point as seen from Position 3.

5.3 Preliminary Results of Truck Tire Whine Measurements

While there are still many questions to be answered about the mechanisms by which tire whine is produced and by which OGA acts to reduce this whine, the recent measurements on the Duke Point Highway provide some preliminary indications of the degree/magnitude of the OGA effect. Figures 5.4, 5.5 and 5.6 show a sample of the narrow band noise spectra recorded at each of measurement Positions 1, 2 and 3. In each case one noise spectrum was captured while the truck in question was entirely on the standard asphalt pavement and one when it was entirely on the OGA. No attempt has been made here to correct for any differences in noise measurement distance or in noise shielding by CRB. The differences in noise levels at the central frequency of the tire tone or whine when on standard asphalt versus OGA are then only indicative of the potential benefit of OGA, but cannot be considered quantitatively accurate.

Figure 5.4 shows two spectra recorded at Position 1 of the noise from an eastbound heavy truck. The upper spectrum was captured when the truck was on the standard asphalt approaching the pavement transition while the lower spectrum was captured when it it was on the OGA. The presence of tire whine in the upper spectrum is indicated by the peak centred in the 437.5 Hz. band. This peak is essentially absent in the lower spectrum.

Figure 5.1; Duke Point Highway Truck Tire Whine Measurements - View of Westbound Truck Approaching OGA/Standard Pavement Transition Point, as Seen from Measurement Position 1.

Figure 5.2: Duke Point Highway Truck Tire Whine Measurements - View of Eastbound Truck Having Just Passed the OGA/Standard Asphalt Transition Point, as Seen from Measurement Position 2.

Figure 5.3: Duke Point Highway Truck Tire Whine Measurements - View of Westbound Truck Having Just Passed the OGA/Standard Asphalt Transition Point, as Seen from Measurement Position 3.

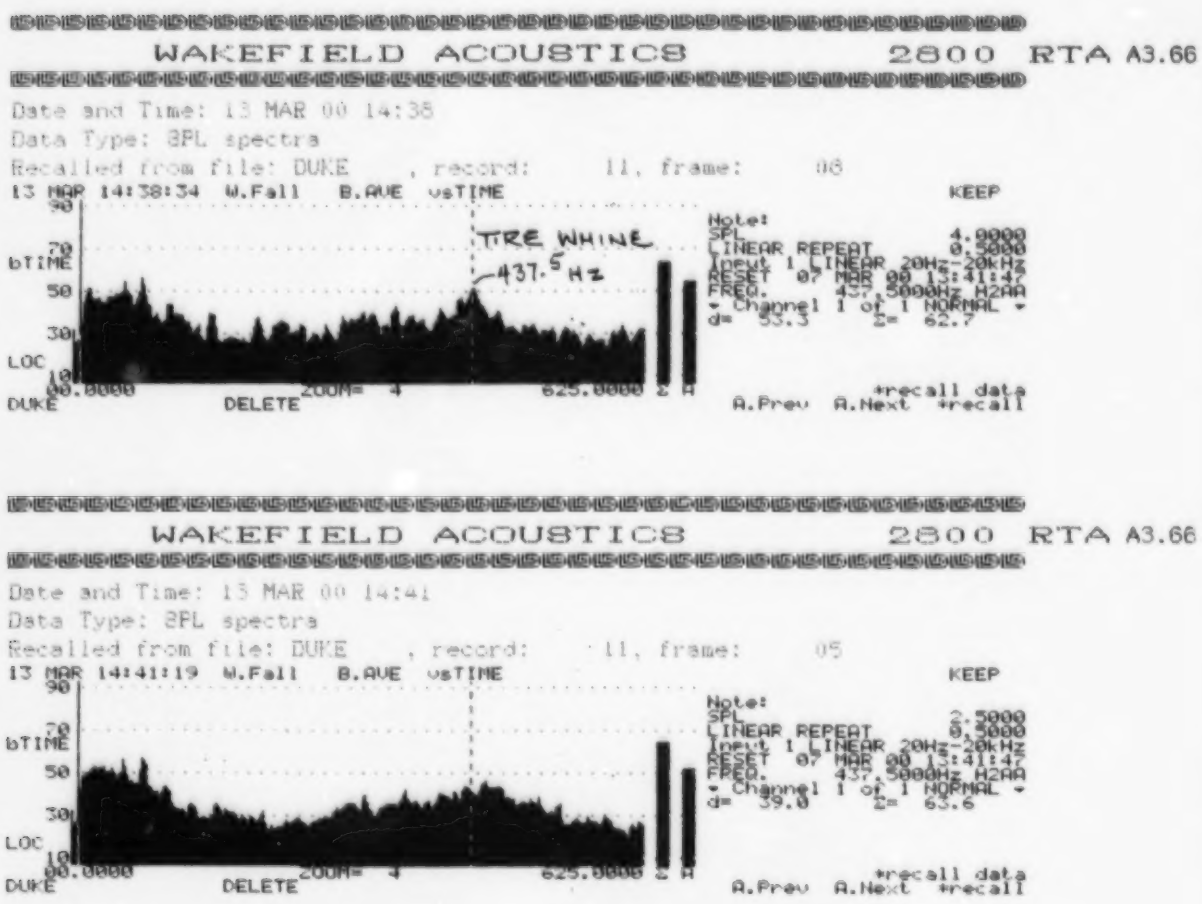

Figure 5.4; Narrow Band (200 Line) Spectra of the Noise Produced by a Heavy Truck Eastbound on the Duke Point Highway as Measured at Position 1, about 200 m South of the Highway. Upper Spectra was Captured when Truck was on Standard Asphalt and Lower Spectra when it was on OGA.

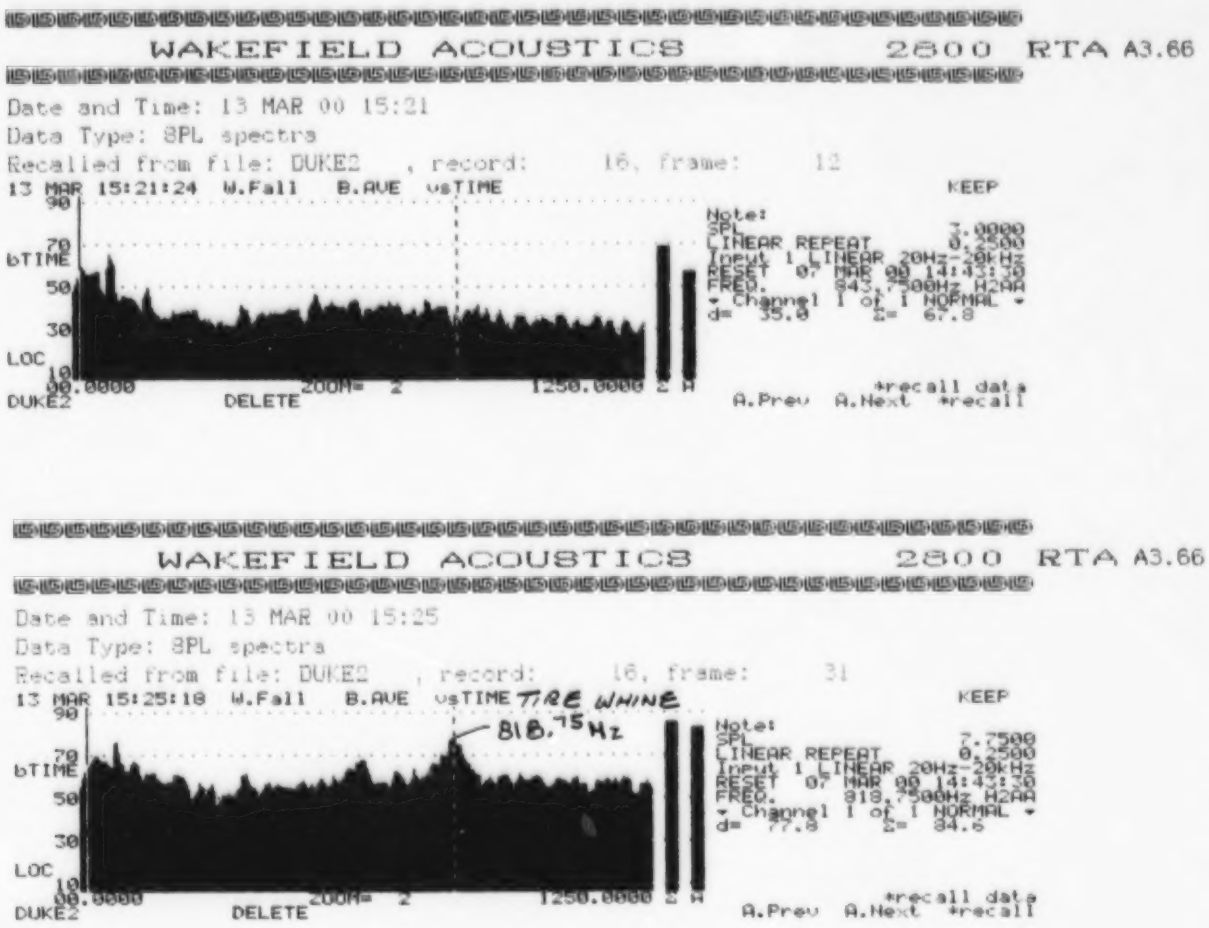

Figure 5.5; Narrow Band (200 Line) Spectra of the Noise Produced by a Heavy Truck Westbound on Duke Point Highway as Measured at Position 2, about 20 m North of the Highway and to well to West of Pavement Transition. Upper Spectra was Captured when Truck was on OGA and Lower Spectra when it was on Standard Asphalt.

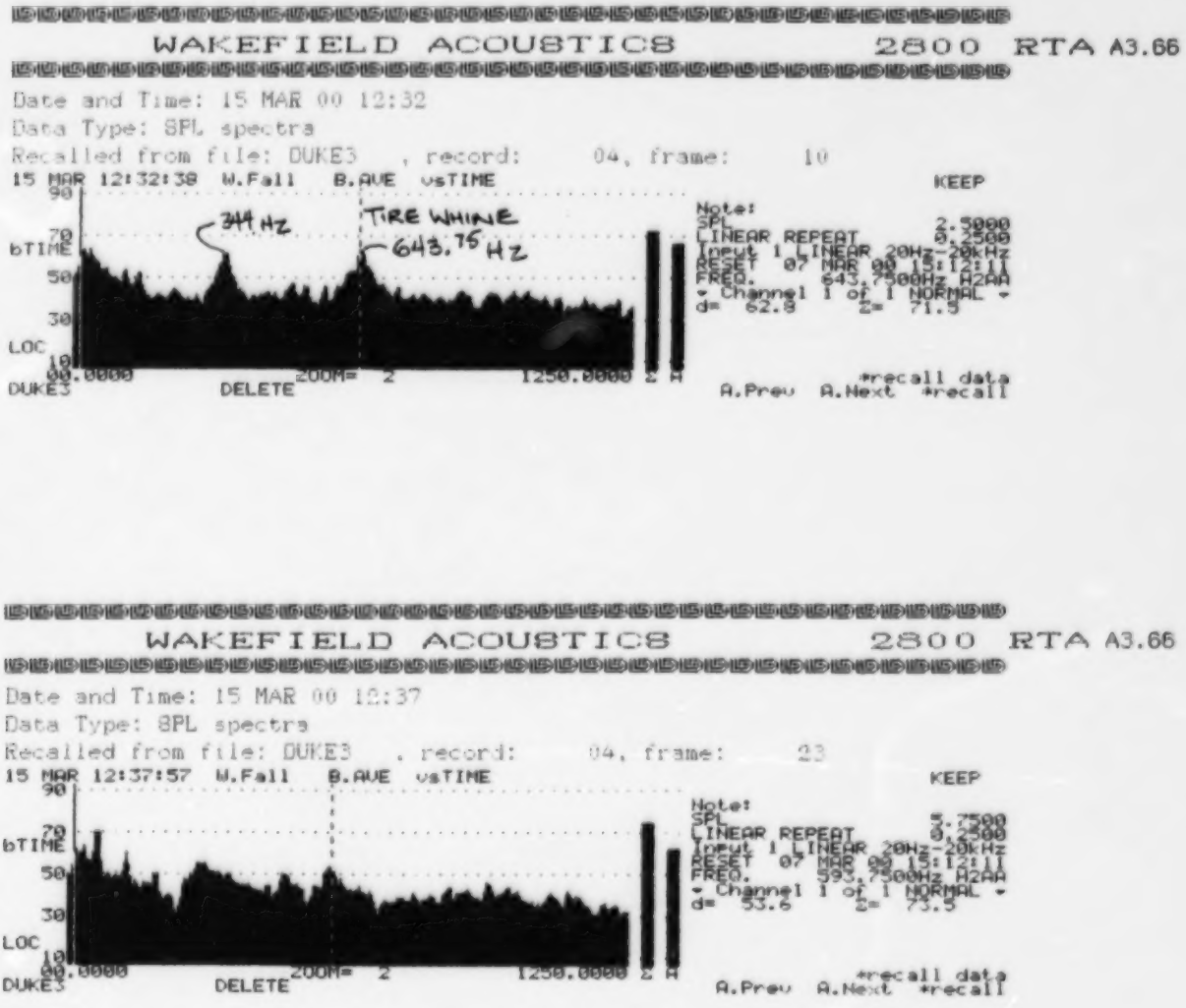

Figure 5.6; Narrow Band (200 Line) Spectra of the Noise Produced by a Heavy Truck Eastbound on Duke Point Highway as Measured at Position 3, about 25 m North of (and below) the Highway and Directly Opposite the Pavement Transition. Upper Spectra was Captured when Truck was on Standard Asphalt and Lower Spectra when it was on OGA.

(Section 5.3 continued)

Figure 5.5 shows two narrow band truck noise spectra measured at Position 2. In this case the truck was heading west so that the upper spectrum was captured first when it was on the OGA and the lower spectrum was captured later when it was on the standard asphalt. A fairly pronounced peak due to tire whine is seen in the lower spectrum centred on the 819 Hz. band.

Finally Figure 5.6 shows two narrow band spectra of the noise from an eastbound truck as measured at Position 3. Here the upper spectrum was captured when the truck was on standard asphalt and displays two strong peaks (both believed to be due to tire whine) centred on the 344 and 644 Hz. frequency bands. The lower spectrum was obtained when the truck had moved onto the OGA. It is seen that a peak still exists near 594 Hz. but it is of much lower intensity. Note that the tire whine was shifted to a somewhat lower frequency (594 versus 644 Hz.). This was cased by the "Doppler Shift" in the pitch of the tire noise due to direction of travel of the truck – in one case moving towards the noise receiver and in the other moving away from it.